Submillimeter Astronomy Investigation of Line Spectra (SAILS) - A Balloon-Borne Instrument

Michael D. Seiffert[a], William D. Langer[a],
Steven D. Lord[b], John Pearson[a], and William R. McGrath[a]

[a]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr., Pasadena, CA 91109, USA
[b]Infrared Processing and Analysis Center, California Institute of Technology, Pasadena CA, USA

ABSTRACT

The Submillimeter Astronomy Investigation of Line Spectra (SAILS) is a balloon-borne experiment under study for a 100 day ultra-long duration balloon mission. The experiment would survey the galactic plane with 1 arc minute angular resolution and 1 km/sec velocity resolution in the important submillimeter lines of CII, NII, and OI. These tracers provide the structure and energetics of major components of the interstellar medium. This knowledge is crucial for understanding the life cycle of the Galactic gas and the processes of star formation and galactic evolution. This instrument's survey of large regions of the galactic plane complements both FIRST and SOFIA which will excel at pointed observations with higher angular resolution and broader spectral coverage. Details of the instrument design and observing strategy are presented.

Keywords: SAILS, Interstellar Medium, Balloon-borne

1. INTRODUCTION

Determining the structure and dynamics of our own Milky Way is the foundation for understanding the past evolution and the probable future of our galaxy. We do not yet know the crucial details and energetics of the structures in our galaxy. In some cases we are getting an exciting glimpse of structures, such as the chimneys that cycle matter from the disk to the halo, but do not yet fully understand the energetics underlying these structures.

Ultimately, we want to understand the evolution of galaxies in general, not just our own. Because of our position inside our galaxy, however, we can map out structures from parsec scales to many kiloparsecs with the modest angular resolution of one arcminute. Understanding the structure, dynamics, and energetics of distant, primeval, poorly resolved galaxies will rely heavily on our understanding of the physical processes in our own galaxy.

The scientific community has or is developing many of the necessary measurements to understand the structure and energetics of the Interstellar Medium (ISM) from the scale of the distance between stars up to the scale of spiral arms. The IRAS 60 and 100 μm measurements probe dust emission, CO measurements probe cold molecular gas, radio continuum measurements probe ionized gas, and HI measurements probe atomic gas. These map most of the galactic plane with angular resolution approaching one arcminute. However, there is a very significant gap in this program which prevents completion of a coherent picture of the galactic ISM – there is no currently planned mission to image most of the galactic plane with high angular resolution *and* high spectral resolution in the most important submillimeter cooling lines of CII and NII.

We are studying a mission concept, the Submillimeter Astronomy Investigation of Line Spectra (SAILS), to fill this gap. These spectral lines are heavily absorbed by the Earth's atmosphere and are not accessible from the ground. The SAILS mission will perform observations possible on a 100 day balloon flight with a state of the art heterodyne instrument. Only a heterodyne instrument can provide the spectral resolution to record the CII and NII emission with the necessary velocity resolution to trace the dynamics of the interstellar gas. This mission could observe a large fraction of the galactic plane (with latitude range $-5\,\mathrm{deg} < b < 5\,\mathrm{deg}$ and longitude range $\ell < 44\,\mathrm{deg}$ and $\ell > 200\,\mathrm{deg}$) with an angular resolution of approximately 1 arcminute and a velocity resolution of 1 km/sec in four

E-mail: Michael.D.Seiffert@jpl.nasa.gov

submillimeter and far-IR lines: NII (122 μm), CII (158 μm), OI (146 μm), and NII (205μm). These tracers provide the structure and energetics of major components of the ionized, photon dominated regions of the ISM

The 100 day balloon flight would circle the earth in the southern hemisphere approximately 5 times at low latitude and at an altitude of greater than 28 km. A launch in the austral summer would provide more daylight hours for the solar panels.

Achieving the goal of understanding the dynamics and structure of our galaxy requires high sensitivity and high spectral resolution. The spectrometer will use a Hot Electron Bolometer mixer to achieve a system noise temperature of approximately 1000 K. The acousto-optic spectrometer backend will have a spectral resolution corresponding to better than 1 kms^{-1}. The local oscillator will use state of the art power amplifiers and multipliers. The detector assembly will view the sky through an off-axis Cassegrain telescope with an effective aperture of approximately 1.3 m. The telescope and detector will be mounted on an inner frame that is in turn mounted in a balloon gondola. For pointing, the inner frame is titled about a horizontal axis to provide elevation control; azimuth control is provided by servoing the entire gondola. The mass of the entire package will be approximately 830 kg, and will require roughly 340 W of power provided by solar panels and batteries.

This mission is a dedicated survey of a large fraction of the galactic plane and is complementary to both SOFIA and FIRST, which will excel at pointed observations with higher angular resolution and broader spectral coverage. If we are to understand the connection between large scale structures and regions of star formation, we require *high spatial dynamic range*, but neither FIRST nor SOFIA is likely to dedicate 100 days worth of observing time to surveying the entire galactic plane.

2. SCIENTIFIC MOTIVATION

2.1. Introduction: the dynamic interstellar medium

What would the Milky Way Galaxy look like viewed face on? What would be the spatial distribution of the various components: the cold neutral (molecular) gas; the warm atomic gas; the hot ionized gas (both the diffuse and dense components); and the stellar distribution? Would extended structures be seen to dominate the disk, such as a spiral pattern, a central bar, rising fountains and bubbles? Would we see cleary defined interface regions, i.e., warm atomic gas between HII regions and molecular clouds? Would these interface regions themselves be extended to fill large volumes, such as interarm regions? And how dominant are the actions of the large scale structures in regulating change in the ISM and initiating the cycling of gas between the different media?

These questions are part of the general problem of how a galaxy maintains interstellar medium (ISM), and what factors lead to evolution of the ISM. Indeed these questions amplify the issues set out as major goals for NASA's Structure and Evolution of the Universe (SEU) program. That is to understand the Energy Cycle, Matter Cycle, and Stellar Cycle of our Galaxy and external galaxies.

We have access to considerably more detailed information on the Milky Way and its closest neighbors than any other galactic systems. We have learned that important processes take place on scales small enough to prevent our isolated observation of them in more distant objects. Detailed pictures of the present physical state of the Milky Way will provide a template for modeling the dominant processes which affect the evolution of the ISM, information crucial to searches for evolution in populations of galaxies at cosmologically-interesting distances.

Over the last couple of decades, infrared and radio astronomy have revealed much about the star formation process by allowing us to probe the interstellar clouds hidden from optical view. We have a fairly good picture of the physics of the process and the regions in which it occurs. Much has also been learned about the return of gas to the ISM, through the study of planetary nebulae, supernovae and supernova remnants, and late-type stellar winds. The molecular clouds in which star formation occurs fill a small fraction of the ISM. But what is the origin of molecular clouds? The reservoir from which the molecular clouds form, and to which the bulk of dying stars return material, is the diffuse interstellar medium. Despite many decades of surveys in the HI 21 cm line, our view of this pervasive component and its development is incomplete; we know very little about the physical conditions in the diffuse ISM, about the interfaces between this medium and the star-forming molecular clouds, even about the distribution of its several phases. These deficiencies prevent us from having a global picture of the dynamically-evolving gas in the Galaxy, the formation and dispersal of star-formation regions, and the development of the Milky Way's disk.

H_2 gas has to be studied by observing trace species that emit efficiently at observable wavelengths. Unfortunately, the lowest emission state of H_2 requires temperatures of a few hundred Kelvin for excitation, while the ISM clouds are very cold (< 100 K.) Traditionally, CO emission at millimeter wavelengths has been used to trace the clouds in the Galaxy. However, a substantial part of the Galactic H_2 gas exists in photon dominated regions where CO is readily destroyed. In these regions, the hydrogen gas is best traced by [CII].

What we need are complete surveys of stars and of the physical conditions in the ISM (mass, size, gas pressure, temperature, magnetic field, ionization state, heating and cooling rate), covering all dynamically significant length scales down to the sizes of star-forming clouds. This cannot be done in more distant galaxies in the local universe, over a broad range of Hubble types, since the telescopes envisioned in the foreseeable future provide insufficient spatial resolution at the wavelengths of important physical probes to study the processes we know are crucial. Nor can it be done with anything less than a survey of a substantial portion of the Galactic disk with angular resolution of order ~1' or better, since the phases of the diffuse ISM seen in HI fill up to 80% of the disk's volume, and exhibit both short (< 1 parsec) and very long length scales, some comparable to the Galaxy's radius (spiral arms). Two-dimensional surveys of the Galaxy's stars (IRAS, 2MASS, IRTS) and dust (IRAS - HIRES) already exist. To measure the three-dimensional distribution of a component of the Galaxy, one must employ observations of spectral lines at whose wavelengths interstellar extinction is small, at spectral resolution sufficient to reveal Galactic rotation and random velocities. Several ground-based, arcminute-resolution observations that can contribute major portions of the complete picture of the life cycle of gas in the galaxy are in progress: the FCRAO CO 2.6 mm galactic-plane survey, the ASTRO [CI] 610 μm survey, and the DRAO Galactic Plane Survey of HI 21 cm.

These surveys, and others planned, however, still lack important information on the distribution and physical state of the ISM. The brightest and most ubiquitous of the spectral lines that can help are certain atomic and ionic fine structure lines lying in the far-infrared spectrum, notably [CII] 157.741μm, [NII] 121.889, 205.178μm, [OIII] 51.815, 88.356μm and [OI] 63.184, 145.525μm. These lines tend to be the brightest in the spectrum of galaxies; the CII line is typically 6600 times stronger than the CO J=1-0 cooling line in galaxies. They include the major coolants of the neutral atomic ISM, the photodissociated periphery of molecular clouds, and most H II regions. They are virtually unaffected by extinction, and can be observed throughout the Milky Way. As discussed below, the lines we have selected to observe are particularly useful in probing the ionized and neutral atomic gas clouds and in deriving crucial physical parameters of these regions.

Observations of these lines in individual sources have been made with airborne platforms such as the KAO, and with the Long Wavelength Spectrotrometer on ESA's Infrared Space Observatory (ISO). Pioneering surveys of [CII] in substantial sections of the Galactic plane have been done with the Balloon-borne Infrared Telescope (BIRT[1]) and the Balloon-borne Infrared Carbon Explorer (BICE[2,3]), and the sky was mapped at 7 degree angular resolution in [CII] and [NII] by the NASA Cosmic Background Explorer (COBE[4]). Unfortunately, none of these experiments provides the combination of sufficient coverage, spatial and (most important) spectral resolution, and sensitivity to complete our picture of the ISM. Indeed only a few [CII] spectra have been obtained with a heterodyne system and thus have high spectral resolution. Because of the scope of this task, Galactic surveys of these lines must be carried out with a dedicated optimized survey instrument. SAILS has been designed to perform this function.

2.1.1. Sub-millimeter and Far-infrared fine structure lines and the ISM

Energy from the interstellar radiation field and cosmic rays is absorbed in the dust grains and gas. The dust grains re-radiate the absorbed energy as far-infrared continuum radiation, while the energy deposited in the gas is radiated in the collisionally-excited lines. Except for very hot or dense H II regions, the lines most easily excited are the infrared fine structure lines of atoms and ions. These lines are among the brightest in the spectrum of spiral galaxies, as is evident in Figure 5. Like most forbidden lines, fine structure lines are generally optically thin; those at far-IR wavelengths are virtually unextinguished as well. Thus they can be used to probe the entire Milky Way disk, unlike lines at visible and ultraviolet wavelengths. For low-resolution observations of the fine structure lines in galaxies the fluxes are dominated by emission from classical H II regions and dense photodissociation regions, but for the Galaxy and its nearest neighbors these regions will be separated cleanly from the widespread components of the ISM at arcminute spatial resolution and high velocity resolution. The brightest and most ubiquitous of them belong to [C II], [N II], and [O I], which will comprise the focus of the SAILS mission.

Table 1 is a list of the spectral line signatures of the various ISM components that illustrates the use of these species in the diagnosis of interstellar gas. The [N II] lines can come only from ionized regions, while [C II] emission will occur both in low-excitation H II (up to ~25% of its total emission) and neutral regions. The bulk of the rest of the [CII] comes from either a dense PDR or the cold neutral medium. Any dense PDR component will also be bright in [O I], allowing these regions to be distinguished easily from the cold neutral medium material. Atmospheric opacity prevents the ground-based observation of virtually all of the far-infrared fine structure lines. Of the four lines SAILS will observe, none are even marginally observable from the South Pole. Some of the lines are observable from aircraft (i.e., SOFIA) but because of the residual telluric absorption and the high ambient temperatures an airborne mission would require thousands of flights to complete the survey that a balloon borne SAILS can do in a couple of months.

ISM Component	Prominent Lines	Weaker Lines
CNM	[C II], H I	CO, [C I]
WNM	HI	[C II], [O I]
WIM	[C II], [N II]	
ELD H II regions	[O III]	[N II], [CII]
Classical H II regions [O III], [N II]		
Molecular clouds	CO, [C I]	
PDRs	[O I], [C II]	H I
SNR shocks	[O I]	[C II], H I
YSO shocks	[O I], CO	[C I], H I

Table 1. Spectral-line signatures of components of the ISM

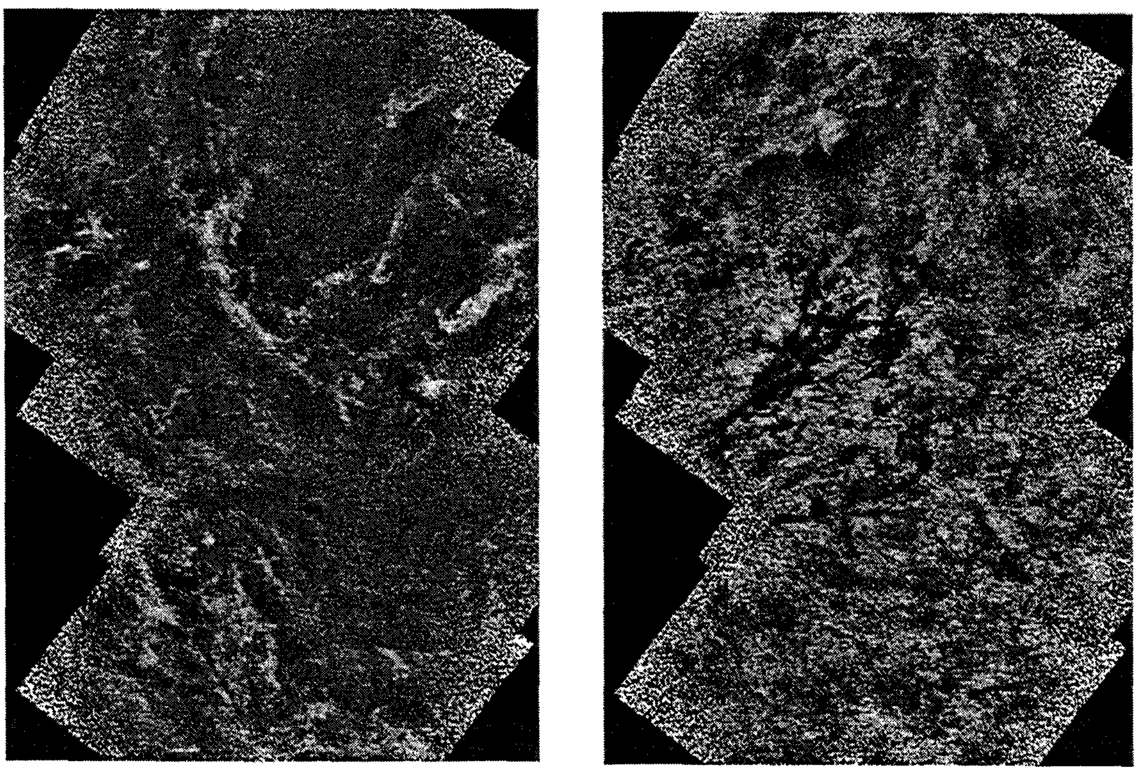

Figure 1. HI observations from the Canadian Galactic Plane survey. The two images are of identical regions, but are spaced 20 km/sec apart in velocity space. These images underscore the need for high spectral resolution.

2.1.2. The need for a complete high -resolution Galactic-plane survey

Structure in the interstellar medium is generally the result either of the growth of local gas-dynamical instabilities, or else derived from the action of global density waves which give rise to spiral arms. The diffuse ISM pervades the disk of the Galaxy, and therefore is susceptible to nonlinear growth of structure on all length scales up to the

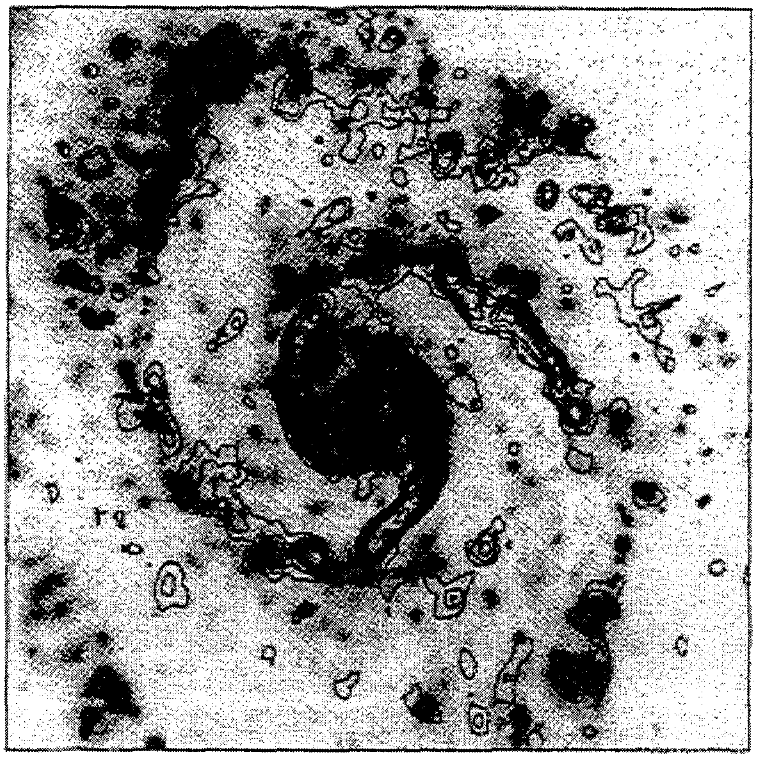

Figure 2. The time sequence of star formation is clearly seen in the disk of the face-on spiral M51, where the CO contours trace the molecular gas, which show a compression on the leading edge of the spiral density wave. Clouds are triggered into forming massive stars, as evidenced by downstream HII regions seen here in Hα emission (grayscale). (From Rand, Kulkarni & Rice 1992).

diameter of the Galaxy itself. Even without properly separating its phases, astronomers have seen structure in the diffuse ISM throughout this range of scales. The Galaxy contains filaments, streamers and spiral arms ranging in length from a few hundred parsecs to less than 1 parsec. Most of the material seen in the HI image shown in Figure 6 lie in a spiral-shock region of the Perseus arm, and exhibits some of the typical substructure within a spiral arm. The smallest structures are unresolved, at <0.6 pc in extent, and the largest are comparable to the map's projected length, 250 pc; visible in the map are organized structures with lengths that span the scales between these limits practically continuously. Similar smaller-scale structure is also present in the interarm diffuse ISM. Consider the example provided by a spiral arm. In order to identify and study in detail the processes responsible for the flux of gas from larger to smaller scales, as in the standard picture of the formation of GMCs from diffuse gas in spiral shocks, one clearly must map the arms completely along their lengths, at parsec-scale resolution. But each of the spiral arms covers a substantial fraction of Galactic longitudes; a survey of a representative sample amounts to a Galactic plane survey. Similar considerations for interarm material yeild the same result.

2.2. SAILS and its capabilities

We have designed SAILS to be capable of detecting, and resolving the spatial and velocity structure, in the diffuse ISM and PDRs throughout the Milky Way Galaxy. As discussed above, the smallest spatial structure observed in the diffuse ISM, and the dimensions of dense molecular clouds, are of order 1 pc; to measure these scales we have chosen a square pixel width of 1 arcminute. To map the largest spatial structures, the spiral arms, the entire Galactic disk must be surveyed, out to several scale heights above and below. For lines of sight toward the more complex parts of the inner Galaxy, the typical Doppler-velocity spacing between clouds is ~ 5 km s^{-1}. SAILS can achieve a velocity resolution of better than $\Delta V = 1$ km s^{-1}

SAILS has been designed to observe four far-infrared spectral lines that are bright and ubiquitous, and provide virtually all of the desired observational distinction and diagnosis of the components of the ISM discussed above: [C II] 157.741 μm, [N II] 121.889 μm, [N II] 205.178 μm, and [O I] 145.525 μm. A summary of the roles these and other related lines play in the analysis of the ISM, and the manner in which they complement the ongoing ground-based H I, CO and [C I] surveys, is given above in Table 1. The ideal sensitivity of the SAILS instrument, assuming a spectral resolution of 1 - 2 km/sec (depending on the frequency of the line), will be 4.4×10^{-17} W/$\sqrt{\text{Hz}}$. The actual sensitivity is likely to be limited by thermal emission from the telescope mirrors. Finding a telescope design that minimizes this thermal emission will be one topic of the mission study.

3. MISSION DESCRIPTION

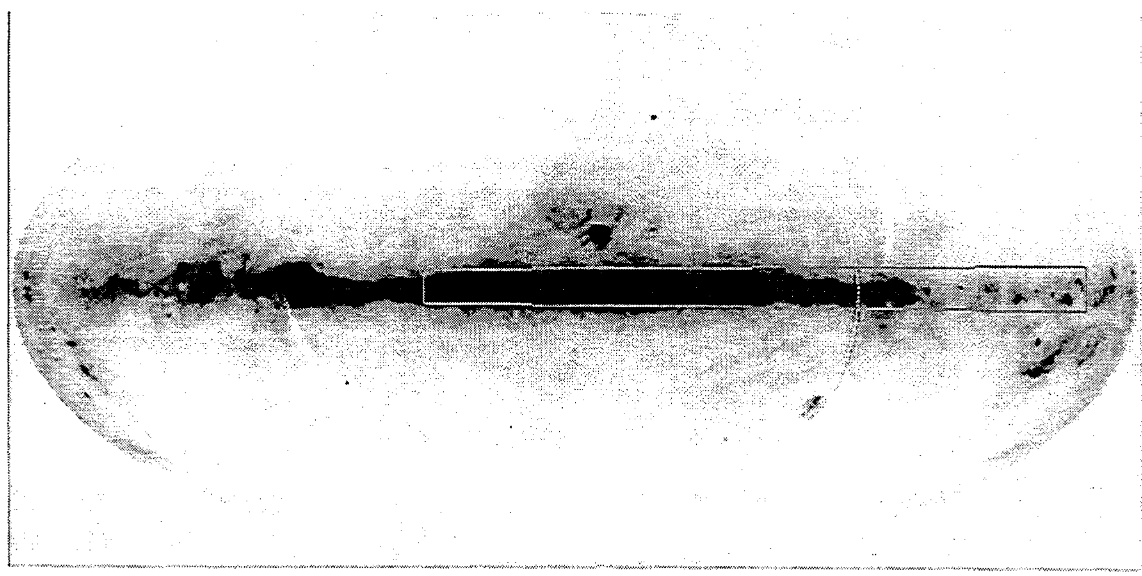

Figure 3. The portion of the galactic plan accessible to SAILS overlayed on the IRAS 100μm map (with zodiacal light subtracted). The region extends from -160 deg $< l <$ 40 deg, -5 deg $< b <$ 5 deg. We will use existing IRAS and low resolution [CII] maps (BICE) to further limit the observations to regions with detectable signal.

3.1. Atmospheric Transmission

Although these lines are heavily obscured from the ground, the atmospheric transmission at frequencies near the spectral lines of interest is excellent at balloon altitudes of 28 km and greater. There is a significant absorbtion feature for the [OI] 145 μm line, but there is still a wide range of velocities for which this line will be unobscured. For this instrument, atmospheric emission does not contribute significantly to the detector background.

3.2. Observing Strategy

The telescope will scan in azimuth and elevation, and will always point at least a 45 deg away from the sun while the sun is above the horizon. The telescope will point at least 30 deg above the horizon and at least 30 deg below zenith to avoid balloon obscuration. A map of the area within 5 degrees of the galactic plane that can be covered with these constraints appears in Figure 3.

Because the total observing time is fixed, there is a tradeoff between galactic plane coverage and limiting sensitivity. The detailed distribution of observing time in various parts of the galactic plane will be optimized during the mission study.

3.3. Ballooncraft

The ballooncraft systems will be highly integrated with the science instrument systems, in constrast to the convential ballooning program. This will reduce mass and power consumption and simplify flight operations. There are many subsystems in this integrated approach; some will be identical to existing, proven designs. Using a standard flight train, for example ensures high reliability. Some systems will be updated; we will use an actively pointed solar array, for example. In all cases we will build on the extensive experience of previous balloon flights (and spacecraft designs where appropriate) to provide a low cost, reliable, and capable solution.

Just as in space mission design, careful attention to payload mass and power margins is important. An estimated mass budget for the payload (exclusive of the balloon) appears in Table 2. We show that, even with the inclusion of a 20% mass margin, we are still comfortably below the ULDB program goal of 1000 kg.

ITEM	MASS (KG)
Frame	**250**
Parachute and Rigging	**50**
Other Balloon hardware	**10**
Primary mirror incl. mounting	**20**
Secondary mirror	**5**
Straylight baffling	**10**
Detector Dewar	**150**
Pointing System: reaction wheel, elevation control	**50**
Computer & Data acquisition hardware	**10**
Sun sensor, star tracker, GPS	**40**
Telemetry	**5**
Solar Panels, batteries, and power system	**80**
Cables	**10**
Reserve (20 %)	**140**
Total	**830**

Table 2. Estimated Mass Budget

An estimated power budget for the payload appears in Table 3. Here we can also see that including the 20% power margin we are still far below the ULDB program goal of 1000 W.

ITEM	POWER (W)
Local Oscillator Subsystem	**15**
AOS	**15**
Computer	**15**
Sun sensor, star tracker, GPS	**20**
Servo system	**150**
Telemetry	**50**
Reserve (20%)	**75**
Total	**340**

Table 3. Estimated Power Budget

3.3.1. Power System

For the ballooncraft power system, we will use a scaled version of the system selected in the ULDB systems definition review. During daylight, a pointed, deployable solar array that is suspended below the gondola frame will provide power for the instrument, ballooncraft systems, and charging batteries. During the night, power will be supplied by rechargable lithium ion batteries. For a power requirement of less than 400 W (including reserves), we estimate

4800 watt-hours of battery capacity with a mass of 55 kg. Charging the batteries and supplying power will require approximately 11 sq. meters of solar panels with a mass of 18 kg. We will also require a 5 kg modular power distribution unit. The ballooncraft bus voltage will be 28±4 VDC.

3.3.2. Telemetry

Our average continuous downlink data telemetry requirement is less than 11 kilobits/sec. We anticipate requiring on the order of 30 uplink commands during the checkout phase of the experiment. No uplink commands are required during normal operation of the instrument; there is only one instrument mode of operation and telescope scanning of the galactic plane will be performed autonomously. The spectra from the AOS will be digitized at 4 Hz with 8 bit resolution with 256 frequency channels. This results in an aggregate instrument rate of 8,192 bit/sec. Approximately 128 bits/sec will be required for pointing, altitude, and timing information. An additional 128 bits/sec will be used for voltage, current, and temperature monitoring of ballooncraft and instrument systems. We will hold approximately 2500 bits/sec in reserve (30 %) for unanticipated needs.

These requirements can be met with a balloon program procured TDRSS transceiver system with a GSFC-developed pointed antenna system. The average TDRSS downlink rate with a pointed antenna is anticipated to be greater than 50 kbits/sec. Power consumption will be 44 W, RF output power will be 5 W and mass is estimated at 5 kg. A nominal uplink rate of 125 bits/sec on a queued basis is available and will be sufficient for commanding.

3.3.3. Mechanical Frame

The inner frame that houses the instrument and telescopes will consist of a welded structure of thin-walled aluminum tubing to provide the necessary combination of strength, stiffness, and low cost. The outer gondola frame will also be constructed primarily from aluminum tubing, but some sections will use a bolted aluminum angle construction for modularity and robustness.

3.3.4. Attitude Control

The inner frame holds the telescope and dewar assembly. It will pivot about a horizontal axis to provide elevation pointing control. A linear ball-screw actuator will drive the frame to the correct angle. Azimuth control will be provided by servoing the entire gondola. We will investigate two options for this azimuth control. A PI-supplied solution would consist of a combination of a motor-driven zero static friction rotator assembly at the top of the gondola (to apply torque against the balloon) and a reaction wheel (for high bandwidth transient response). The alternative is a previously demonstrated WFF supplied rotator. One option will be selected before the PDR based upon pointing stability and mass and power requirements. We note that we do not require attitude *control* to a fraction of a beamwidth; only attitude determination is required at this accuracy. The attitude control requirement is simply that each part of the region of interest is covered with adequate integration time. One arcminute pointing in azimuth and elevation control will be adequate.

Typical balloon pendulations are of order a few arcminutes. This can result in a non-zero gondola cross-elevation angle, and therefore non-zero telescope roll angle. Because we have a relatively symmetric beam pattern, we will not be affected by a small roll angle.

3.3.5. Attitude Determination

A combination of sensors will be used to provide the required attitude determination of approximately 20 arc seconds. An attitude GPS system will be used to provide coarse positioning with an accuracy of 4 arc minutes and an update rate of 10 Hz. It will also provide latitude, longitude, and timing information for the pointing algorithm. A sun sensor mounted to the gondola frame will provide 20 arc second pointing information during the daytime. A precision angle encoder on the elevation bearing assembly will measure the elevation angle between the telescope in the inner frame and the sun sensor on the outer gondola frame. A star tracker co-aligned with the telescope pointing direction (mounted on the inner frame) will provide night-time pointing information. The small residual offset angle between the telescope and the star tracker will be calibrated before launch. The orientation of the sun sensor will calibrated relative to the star tracker before launch.

3.3.6. Computer & Software

We will use a 486 class, PC-104 compliant computer for ballooncraft systems control, data acquisition from the science instrument, and interface to the telemetry system. This rugged, industrial standard now has extensive ballooning heritage and combines low cost with an extended operating temperature range and high reliability. We will keep development of the on-board software to a minimum by making extensive use of flight code from previous pointed balloon platforms. We will use a real-time multitasking operating system designed for embedded industrial computers. Hermetically sealed commercial hard drives will be used for on-board data storage. We expect the flight to generate approximately 12 Gbytes of total raw data, which will be telemetered to the ground and stored on-board for redundancy. We will store the operating system and flight code on PROM as well as hard disk. We expect this system to consume approximately 15 W; the mass will be less than 10 kg.

3.4. Telescope

The Telescope will be an off-axis Cassegrain design with an effective aperture of 1.3 m. The off-axis design minimizes thermal emission from the telescope, reducing the detector background. We will under-illuminate the primary to further reduce the thermal background from radiation diffracting from the edge of the mirror. The beam size (FWHM) at the lowest frequency line (NII 205 μm) will be approximately 1 arc minute. The primary mirror will be fabricated from carbon fiber composite to reduce mass, and will have a surface rms of less than 6 μm. The mass of the primary alone without mounting structure will be less than 14 kg. We will design our optical system to make use of an existing mold for the construction of the primary, thus reducing cost significantly. We will use a light weight machined aluminum mirror for the secondary, to reduce cost. The entire telescope assembly will be surrounded by a light weight baffle constructed from thin sheet aluminum. This baffle will extend far enough to prevent the sun from directly illuminating the surface of the primary when the telescope is pointed more than 45 degrees away from the sun. The baffle will also be constructed so that the sun cannot directly illuminate the instrument dewar through only a few internal bounces in the baffle itself.

3.5. Instrument

The instrument is a 1.4 - 2.4 THz heterodyne receiver coupled to an acousto-optic spectrometer backend through a low-noise intermediate frequency amplifier. The heart of the heterodyne receiver is a Hot Electron Bolometer (HEB) mixer. Most key aspects of the SAILS instrument are already being developed at JPL.

3.5.1. Detectors

The high spectral resolution and high sensitivity of this instrument is possible through the use of a HEB mixer front end. HEB mixers represent a revolutionary improvement in receiver technology for this frequency range. HEB mixers have much lower system noise temperature and lower LO power requirements compared to Schottky diode mixers. They have better spectral resolution and better throughput compared to an incoherent detector with a Fabry-Perot filter.

3.5.2. Local Oscillator

A stable local oscillator (LO) signal to drive the mixer will be provided by a series of multipliers and amplifiers. We require approximately 100 nW of power to be deposited in the mixer. We will leverage the results of the JPL technology development effort for FIRST to meet the schedule and cost contraints.

3.5.3. Instrument Dewar

A 100 liter liquid helium dewar will cool the HEB mixer to less than 2 K. A precision pressure regulator on the helium gas outflow will limit pressure (and therefore temperature) variations at float altitude. The resevoir of liquid helium will be sufficient for 100 days of operation. The helium boiloff gas will be used to cool the outer layers of shielding.

3.5.4. Backend Spectrometer

We currently plan to use an acousto-optic spectrometer (AOS) system for the backend spectrometer. We will need a 2 GHz total bandwidth and approximately 200 channels. Similar technology is being employed by SWAS, ODIN, FIRST, and SOFIA.

3.6. Mission Operation

The SAILS mission operation will emphasize robustness and low cost. All planning and scheduling of observations will be performed before the balloon launch. Ballooncraft and instrument integration and test will take place at the Wallops facility. The instrument, support electronics, and major ballooncraft subsystems will be thermal vacuum tested. RF compatibility tests will be performed and a telemetry test of the integrated package will be performed.

At the Southern Hemisphere launch site (expected to be Alice Springs, Australia), members of the science team familiar with the instrument working together with WFF will perform a final check of the instrument and ballooncraft systems, top off the cryogens, and turn the package over to NSBF personnel for launch. A standard crane launch technique with careful balloon inflation metering is expected.

Once the ballooncraft reaches float altitude, initial checkout and calibration will be performed by the science team. Subsequent observations will consist of scanning the telescope over the desired regions of the galactic plane and will take place autonomously.

NSBF will be responsible for continuous flight management and trajectory analysis through a flight operations and management facility located in Palestine, TX. Initial post-launch control, however, will be conducted with line-of-sight communications from the launch site. Commands to the ballooncraft for flight termination, ballast operations, and other flight operations will be generated by NSBF as needed. They will be responsible for collecting downlink telemetry and sending uplink commands through TDRSS. Downlink telemetry data will be delivered to the science team via the internet. Commands to the science instrument will only be necessary during the checkout phase and to respond to any anomolies. These commands will be generated by the science team and then passed to NSBF for uplink.

Dry-land payload recovery will be attempted and will be performed by NSBF personnel assisted by a member of the science instrument team.

3.7. Information System

We will draw upon expertise at the Infrared Processing and Analysis Center (IPAC) to operate a data pipeline system. Because all the observations will be performed in the same mode (scanning the telescope), this pipeline will be quite simple.

We will produce a final data archive that will consist of: 1) the final science data product, 2) calibrated time series science data, 3) time series ballooncraft data including pointing, balloon location, and instrument and ballooncraft engineering data, 4) a list of uplinked commands and timestamps, and 5) the raw downlink telemetry. We expect that the size of this archive for the entire mission to be less than 80 Gbytes and will be handled by a single workstation.

The final science data product will consist of a "data cube" in each of the four spectral lines. Each data cube will be a map of the galactic plane in latitude-longitude coordinates with the third dimension being the slices in velocity space. This data product will then form the foundation for further scientific investigations including attempting to construct a three dimensional map of the galaxy and determining the nature of galactic structures.

4. CONCLUSION

We have described a mission concept study for a balloon-borne mission to image part of the Galactic plane in the important submillimeter cooling lines. We are now in the process of studying the implementation of such a mission and performing detailed analysis of the various instrument and ballooncraft subsystems. If this mission is selected in the future for funding, it will add greatly to our undertanding of the dynamics and physical conditions of the interstellar medium.

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